GenFit + Geant4e Kalman Filter Tracking: One option for f/sPHENIX tracking

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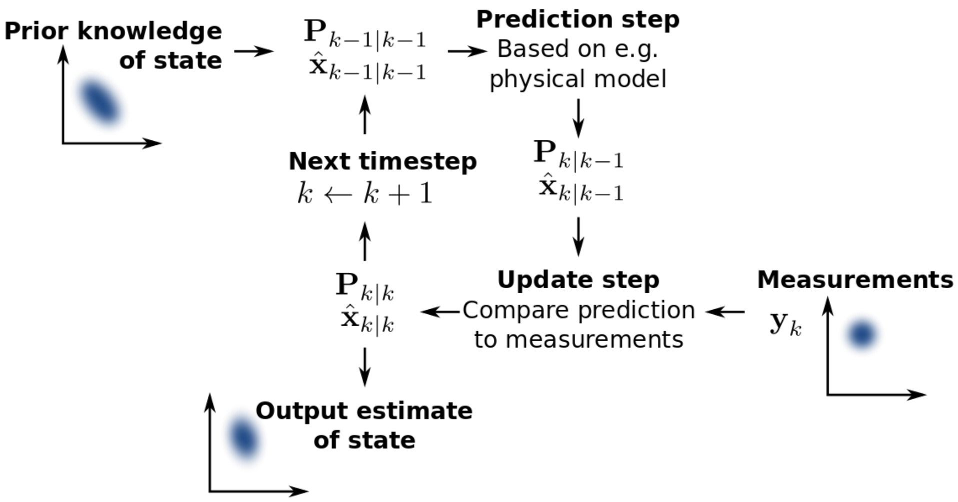
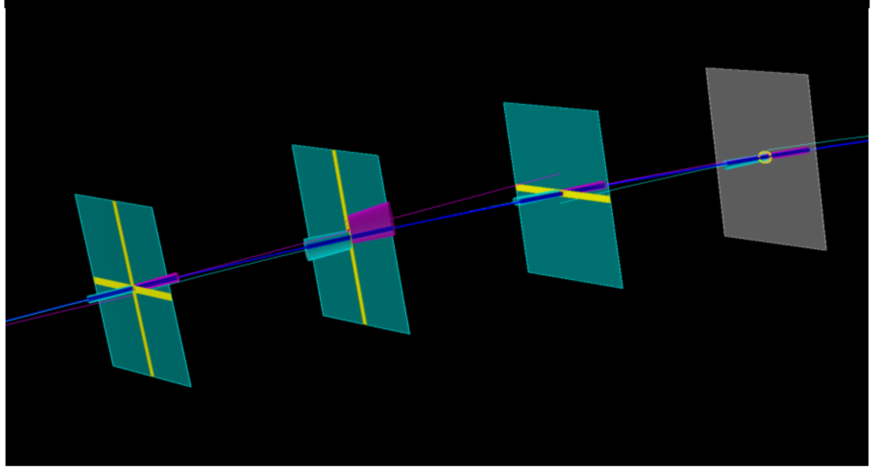
Kalman Filter Tracking with GenFit and Geant4e

- Kalman Filter Tracking is a linear weighted combination of measurements and predictions.
- Fitting Algorithm: GenFit is an Experiment-independent, modular track-fitting framework.
- Error Propagation: Geant4e is an error propagation package include the GEANT4.



GenFit Event Display:
Smoothed track: weighted average between forward fit and backward fit



GenFit

- Developed for PandaRoot, and have been used in several experiments: . Belle II, PANDA, SHiP, AFIS, GEM-TPC, FOPI, ...
- GenFit de-couples the Fitting Algorithm with Specific Detector Setup.
- This is done by delegate the state/error propagation to the Track Representation (AbsTrackRep)

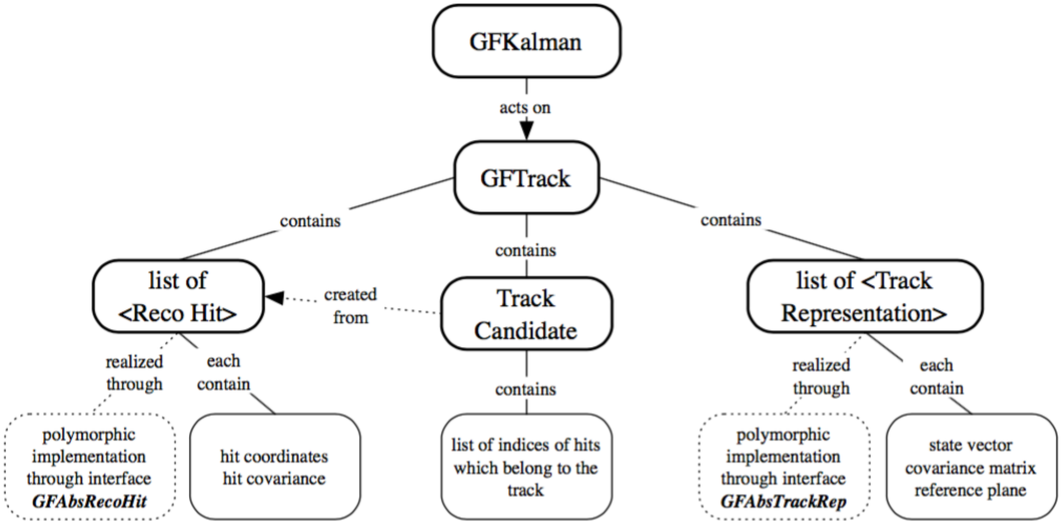


Figure 1.1: General structure of GENFIT.

http://genfit.sourceforge.net/GENFIT_v1_2.pdf

From Geant3 to Geant4

- In the current GenFit, a default TrackRep called RKTrackRep was implemented.
- It was adapted from COMPASS and has been used successful in other experiments. (e.g. Belle II).
- The biggest caveat to use that in f/sPHENIX is that is was based on TGeo. And f/sPHENIX would use Geant4. It may cause problem/difference if we want to translate.
- So a new TrackRep based on Geant4 is needed.

RKTrackRep:

- Use TGeometry to describe the detector/field
- Propagate through magnetic field: Runge-Kutta method
- Material effect (energy loss, multiple scattering, etc.): GenFit's own calculation.

G4eTrackRep:

- Use Geant4e to handle state/error propagation, just feed Gean4e with a G4 detector:
- Propagate through magnetic field: Runge-Kutta method implemented in Geant4
- Material effect (energy loss, multiple scattering, etc.): Geant4's calculation

Geant4e

Geant4e in Geant4 is the successor of GeanE in Geant3. And it does pretty much same thing: propagator track parameter and error matrix from one detector part to another.

Basic structure:

- Initialized with a Detector setup.
- G4eTrajState (particle type, position, momentum, errors)
- G4eTarget
  - Surface: G4eTargetPlaneSurface, G4eTargetCylindrycalSurface, etc.
  - Length: Stop until a certain tracking length
  - Volume: Track is propagated until the surface of a GEANT4 volume

Detailed introduction to Geant4e:

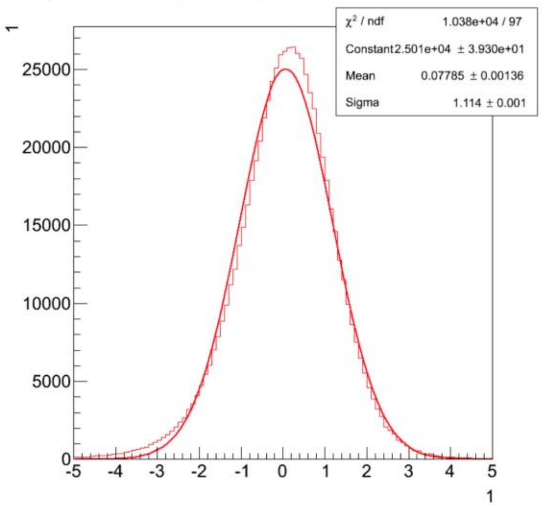
GEANT4E talk, Pedro Arce:

https://geant4.web.cern.ch/geant4/results/talks/CHEP06/CHEP06-GEANT4E.pdf

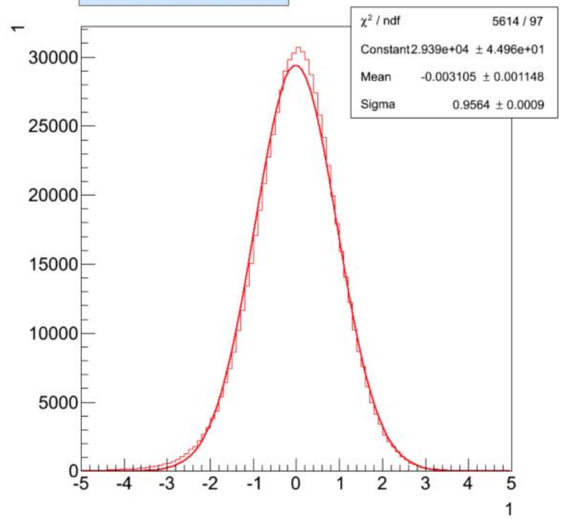
Geant4e already included in Geant4 already.

Pull of 1/P : Momentum Parameter

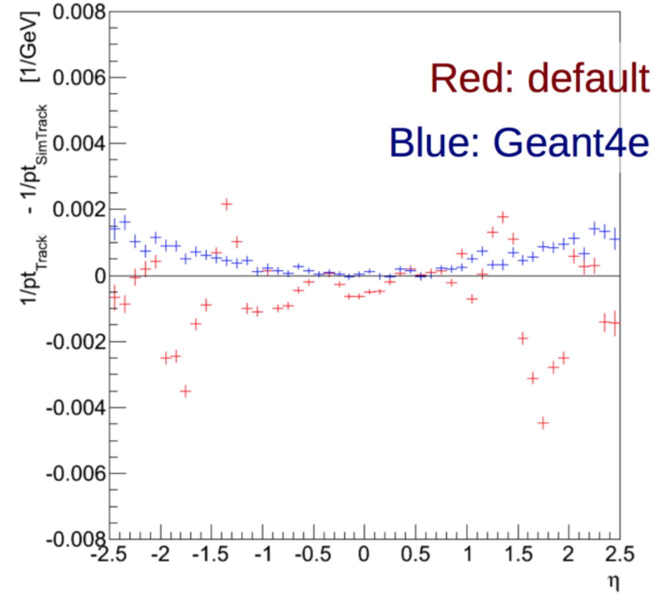
regular



Geant4e



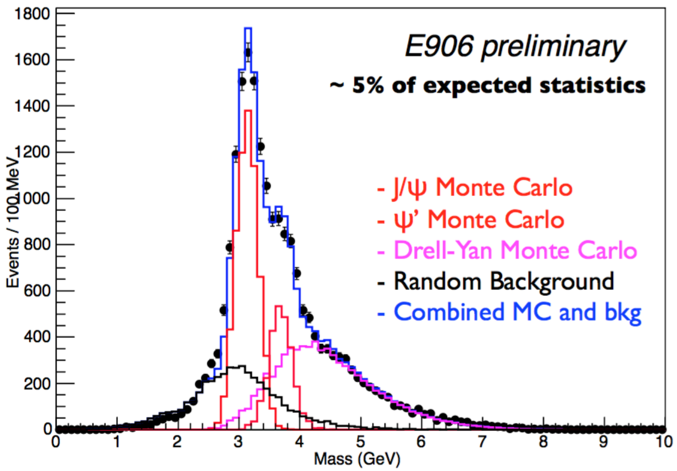
1/pt residual over Eta



- The Geant4e material model is able to achieve a better mean (0.0779 vs. -0.0031) and sigma (1.114 vs. 0.9564) than the regular method
- In this momentum regime, errors on the momentum are modeled well

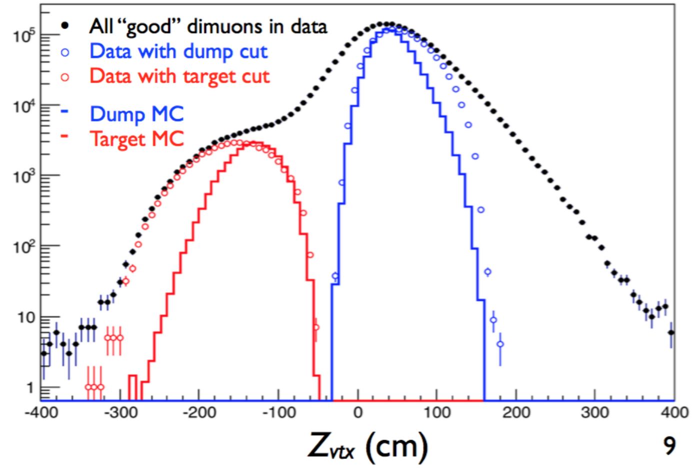
T. Hauth's talk @ LPCC Detector Simulation Workshop, Mar 2014
For the purpose of cross-check/improve the CMS default material simulation

Data from FY 2014 (Run-II)



- Monte Carlo describe data well
- Resolution better than expected
  - $\sigma_M(J/\psi) \sim 180$ MeV, $\sigma_M(DY) \sim 220$ MeV
  - J/ψ ψ' separation
  - Cleaner DY sample
- Good target/beam dump separation

- Beam quality worse than expected (instantaneous rate much higher than average)
  - live time of spectrometer greatly reduced by the 'super' RF buckets
  - Reconstruction efficiency lower than expected because of the high detector occupancy



- Entire beam interacts upstream of SeaQuest spectrometer
- Pointing resolution very poor along beam axis
- Dominated by random coincidences

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K. Liu's talk @ Fermi Lab's User meeting, Jun. 2015
Shows much better Jpsi/psi' peaks.

Test Geant4e in a standalone way:

Kun's E906 work: TrackExtraplator:

- A interface from detector coordinate system to curvilinear coordinate system.

Geant4e version:

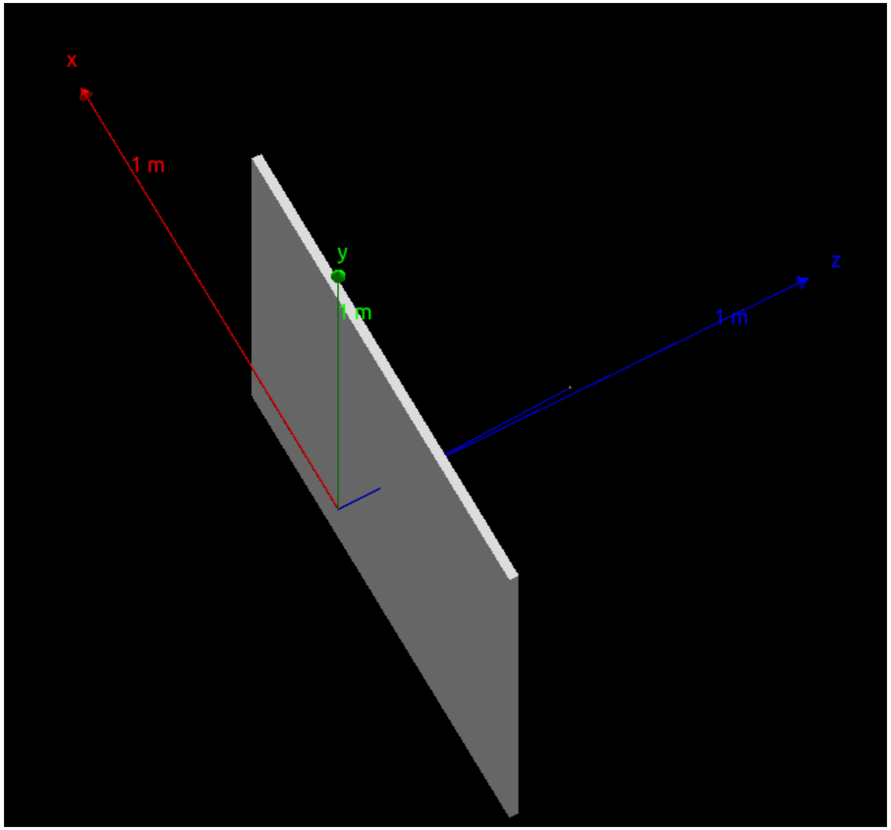
- Geant4.10.1-p02

Detector Setup:

- G4_Galactic in the World.
- A Pb/Al sheet perpendicular to z axis. (9-11cm)
- Magnetic field along x axis. (Sometimes turned off)
- μ+ injected from (0,0,0) with momentum(1MeV, 0, 10GeV)
- * error if set px to 0.

Track State vector: (1/p, px/pz, py/pz, x, y)

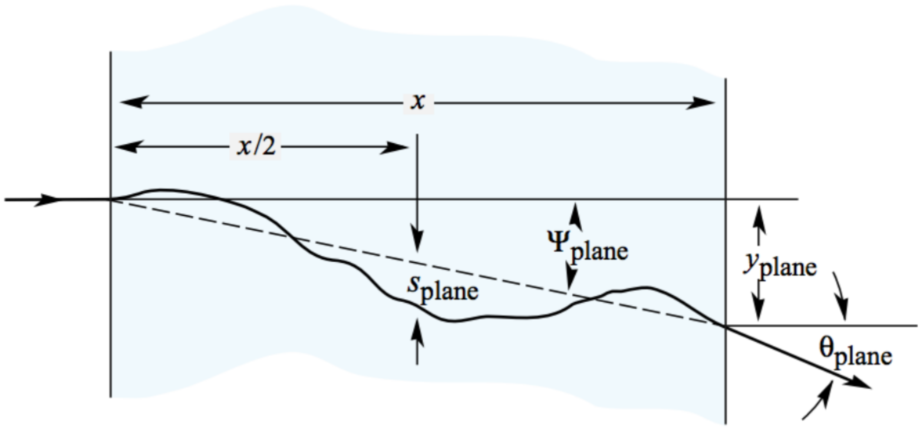
- z used as the propagation position indicator.
- Units: cm, GeV
- In the TrackExtrapolator::print(): mm, MeV



Multiple Scattering through Material

$$\theta_0 = \frac{13.6\ \mathrm{MeV}}{\beta c p} z \sqrt{x/X_0}\Big[1 + 0.038 \ln(x/X_0)\Big]$$

$$y_{\mathrm{plane}}^{\mathrm{rms}} = \frac{1}{\sqrt{3}} x\, \theta_{\mathrm{plane}}^{\mathrm{rms}} = \frac{1}{\sqrt{3}} x\, \theta_0 \ ,$$



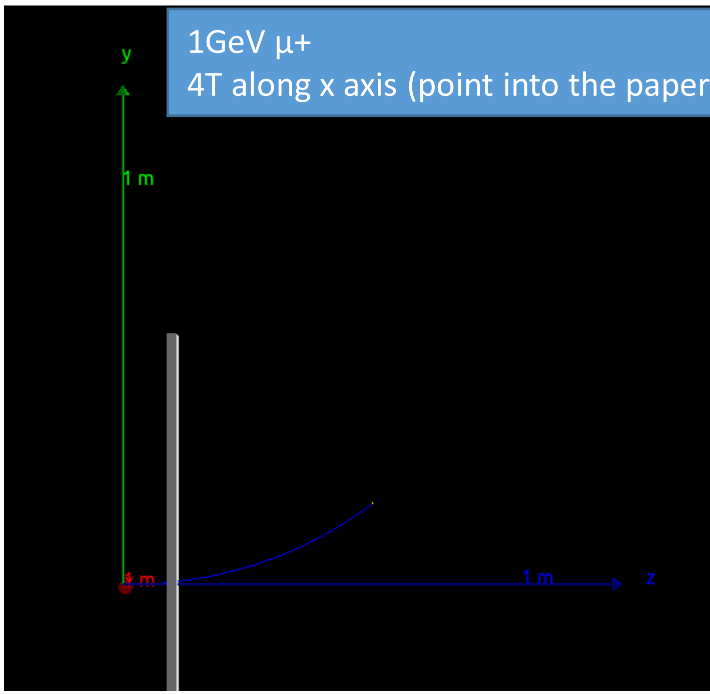
2cm Pb, 10 GeV mu+	Calculation	Geant4e
θ0	0.0027	0.0026
y0 / cm	0.0031	0.0030

2cm Al, 10 GeV mu+	Calculation	Geant4e
θ0	0.00061	0.00065
y0 / cm	0.00070	0.00074

Track propagation in Magnetic Field

Seems there is some unit problem in this test.
The bending is only 1/100 as expected.
Debugging now.

1GeV μ+
4T along x axis (point into the paper)




```
Propagating
From (0,0,50) to (0.001,0.00311784,60)
Momentum change: (1,0,10000) to (1,5.99585,10000)
Initial error matrix:
0  0  0  0  0
0  0  0  0  0
0  0  0  0  0
0  0  0  0  0
0  0  0  0  0
Final error matrix:
4.17651e-61  -8.81481e-64  4.63035e-61  4.53756e-65  -1.76296e-64
-8.81481e-64  2.93904e-33  -2.46272e-31  -1.71507e-34  4.40953e-34
4.63035e-61  -2.46272e-31  2.3839e-26  5.37648e-30  -5.07014e-31
4.53756e-65  -1.71507e-34  5.37648e-30  1.31025e-33  -1.62453e-34
-1.76296e-64  4.40953e-34  -5.07014e-31  -1.62453e-34  2.58265e-34
Printing the content of matrix: initial error matrix
The matrix has 5 rows and 5 columns.
Line 0:  0  0  0  0  0
Line 1:  0  0  0  0  0
Line 2:  0  0  0  0  0
Line 3:  0  0  0  0  0
Line 4:  0  0  0  0  0
Printing the content of matrix: final error matrix
The matrix has 5 rows and 5 columns.
Line 0:  4.17651e-61  -1.32616e-64  9.15775e-64  -1.5755e-65  1.81359e-64
Line 1:  -1.32616e-64  8.60114e-33  -1.09404e-33  3.11383e-33  -7.53984e-34
Line 2:  9.15775e-64  -1.09404e-33  3.14647e-33  -6.17295e-34  5.95309e-34
Line 3:  -1.5755e-65  3.11383e-33  -6.17295e-34  1.22906e-33  -3.24364e-34
Line 4:  1.81359e-64  -7.53984e-34  5.95309e-34  -3.24364e-34  3.39457e-34
```

10GeV μ+
2 tesla magnetic field along x axis

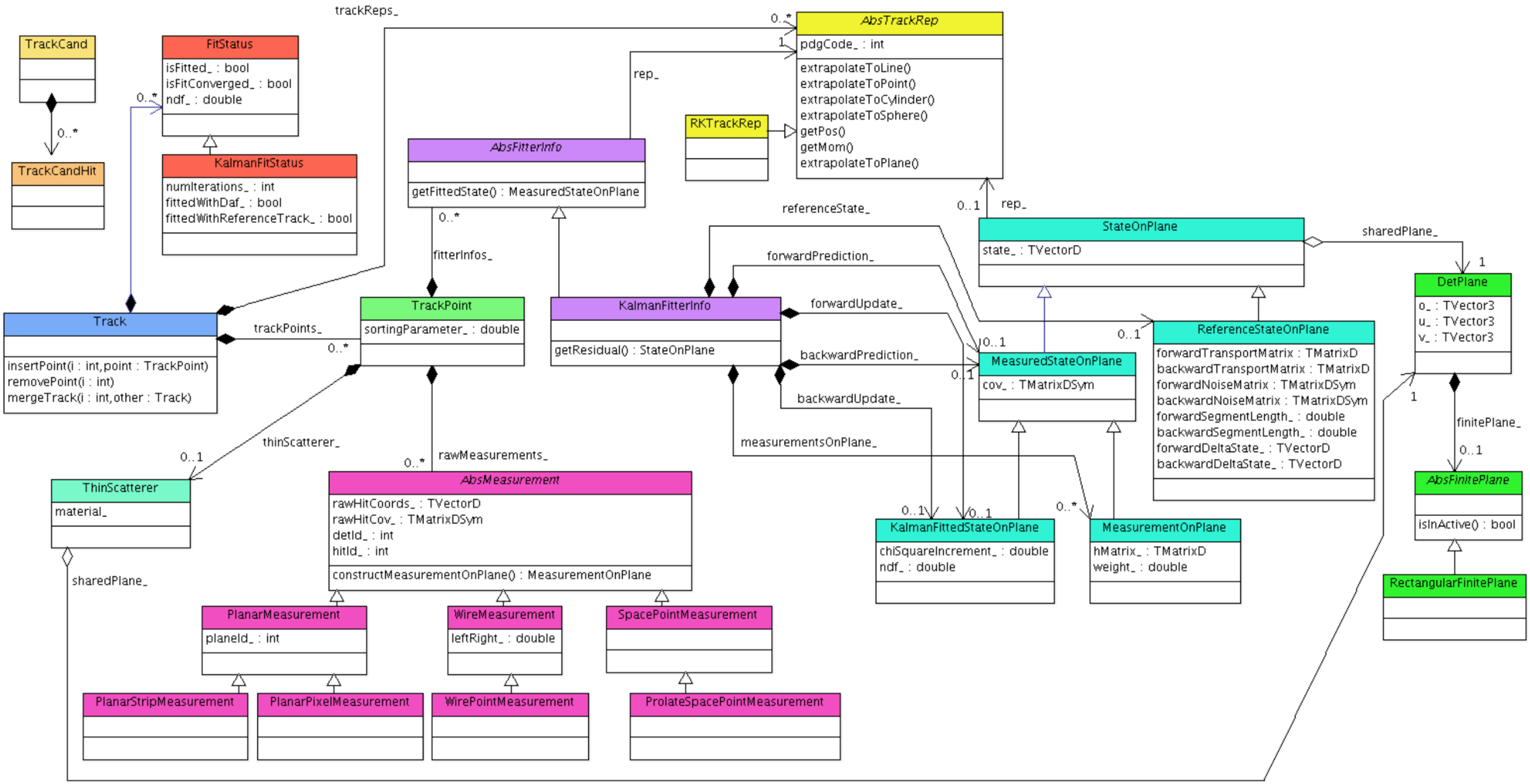
Summary

- Explored the option of using generic tools for the f/sPHENIX tracking.
  - GenFit: successfully used in many experiments. By default only has TrackRep based on Geant3.
  - Geant4e: distributed with Geant4. Studied by several experiments and proved to be working well in E906.

- Current Status:
  - Standalone Geant4e track extrapolator (From Kun's E906 work) tested.
    - Some unit problem under debugging.
  - Currently implementing the G4eTrackRep.
  - Alpha version should be available in a couple of weeks.

Backups

Data structrue of GenFit 2



Scenario 1: 0 Error Matrix Propagation in Vacuum

- 0 Error Matrix remained 0.
- Green box indicate the output of TrackExtrpolator::print()
- Yellow box indicates the the input and output err. matrix in SD system